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Trainability of Abilities:

Training and Transfer of Spatial Visualization

Jerrold M. Levine
David Schulman
Rae E. Brahlek
Edwin A. Fleishman

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require for successful task performance the abilities being trained. Results indicated that training did not significantly enhance spatial visualization as measured by a standard ability test administered before and after training. There was no evidence that performance on the transfer tasks was affected significantly as a result of training (i.e., there was no transfer of training). There was no differential retention between trained and untrained groups.

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TRAINABILITY OF ABILITIES:
TRAINING AND TRANSFER OF
SPATIAL VISUALIZATION

Jerrold M. Levine
David Schulman
Rae E. Brahlek
Edwin A. Fleishman

TECHNICAL REPORT

Prepared under Contract to the
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April 1980

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ABSTRACT

The feasibility of training spatial visualization so as to facilitate transfer among tasks requiring this ability was undertaken. Eighty undergraduate college students participated in a study of from one to five days duration. Experimental subjects received extensive practice with feedback provided on a set of tasks known to require spatial visualization. Control subjects received no practice. All subjects were tested on two transfer tasks which were dissimilar to the training tasks but which required proficiency in spatial visualization for successful task performance. Results indicated that training did not significantly enhance spatial visualization as measured by a standard ability test administered before and after training. There was no evidence that performance on the transfer tasks was affected significantly as a result of training (i.e., there was no transfer of training). Furthermore, there was no differential retention between trained and untrained groups.

INTRODUCTION

The need for more flexible and adaptable Navy personnel capable of performing a broad range of Navy tasks and jobs is receiving increased recognition. A number of factors contribute to this trend, including the possibilities of fewer billets and smaller crew sizes, and the increased complexity of Navy jobs. Additionally, the impact of automation in man-machine systems has been to enhance the responsibility of the reduced number of personnel manning and maintaining these systems.

The purpose of the present research was to examine the feasibility of training spatial visualization so as to facilitate transfer among tasks requiring this ability, and therefore, reduce training time and increase personnel flexibility. Abilities are broad capacities underlying performance in complex skills and related to performance in a variety of tasks and jobs (Fleishman, 1972). Thus, spatial visualization is basic to performance on such diverse tasks as navigation, blueprint reading, and dentistry. If general abilities, such as spatial visualization, can be improved through the use of diversified and extensive training, then this improvement should generalize to a variety of tasks and jobs in which the abilities are involved. Ability training may provide a more efficient approach for training individuals to perform a variety of different tasks than training for each specific task.

The notion that human abilities can be improved through training has not been explored extensively. Most abilities are considered to be the product of earlier learning and genetic factors (Ferguson, 1956; Gagné & Fleishman, 1959), and are defined as relatively stable attributes in the adult (Fleishman, 1972). However, there is some evidence

that spatial visualization can be enhanced by diversified training. Brinkman (1966) provided extensive training in the behaviors thought to be involved in spatial visualization (i.e., discrimination, recognition, organization, and orientation), and found significant improvement, on a spatial relations criterion test administered before and after training, for the trained group but not for an untrained control group. Stringer (1975) attempted to enhance spatial ability using various drawing training procedures and found that trained groups did better than an untrained control group on a test of spatial relations, but only when there was content similarity between the training and testing materials.

McGee (1979) in an intensive review of the literature on spatial abilities, found conflicting evidence concerning the improvement in performance as a function of controlled practice. He points out that Blade and Watson (1955) reported significant increases by students on a test of spatial visualization during an engineering course, and Dailey and Neyman (1967) found positive effects of training similar to those of Brinkman (1966). On the other hand, studies by Faubian, Cleveland, and Hassell (1942), Myers (1958), Ranucci (1952), and Brown (1954) have failed to find increased performance on spatial visualization tests owing to training in relevant tasks such as drafting, blueprint reading, engineering drawing, mechanical drawing, and geometry.

The evidence suggests that spatial visualization is a modifiable ability, but mixed results have occurred as a result of previous training attempts. Difficulties in specifying the relevant activities for

improving spatial visualization undoubtedly contribute, and the limits placed on the potential spatial performance by hemispheric specialization cloud the issue. Nonetheless, systematic attempts to train spatial visualization have potential for success.

There is little doubt that performance on a task can be enhanced by training on similar tasks. Postman (1971) has reviewed the extensive literature on the direct relationship between task similarity and transfer of training. The major concern of the present study, however, is whether or not the training of an ability using a variety of tasks and materials, which are relatively dissimilar to a criterion task can enhance performance on the criterion task. In order to demonstrate such a phenomenon, it is necessary to select training materials and criterion tasks which tap the identical ability, but which are otherwise dissimilar. In this fashion, any improvement which might result from training could not be attributed to the similarity between training and criterion tasks. Instead, improvement could be inferred to have resulted from the enhancement of the ability through training and the positive transfer of this training to the criterion task.

A recently completed review of the literature (Hogan, 1978) relevant to training abilities revealed no other controlled test of whether or not ability training can ultimately transfer positively to dissimilar tasks requiring the same abilities. The early work at the beginning of this century was most directly related to this issue, but was fraught with methodological difficulties which precluded conclusions from being drawn (see Postman, 1971).

There is evidence, however, from other areas of research employing transfer paradigms which suggests that "nonspecific" transfer does, in fact, take place. Research on learning to learn has reported positive transfer when there was only minimal similarity between training and criterion tasks (Duncan, 1953, 1958; Posner & Keele, 1968). Additional support comes from simulation efforts which demonstrate that highly generalized training simulators promote transfer to very specialized tasks. Further, educational researchers have reported modest success at training intellectual abilities (see, for example, Parnes & Noller, 1972; and Maltzman & Morrisett, 1952).

A recent investigation of the feasibility of training selected abilities in order to facilitate transfer among tasks requiring these abilities was carried out by Levine, Brahlek, Eisner, and Fleishman (1979). This study was concerned with training flexibility of closure and spatial scanning abilities, and testing for transfer to an electronic troubleshooting task in which those abilities had been shown to be dominant factors. Subjects received extensive practice with feedback on a variety of tasks known to require the abilities of flexibility of closure and spatial scanning. They were then tested on the electronic fault-finding task (a task dissimilar to the training tasks). The results revealed significant enhancement of the spatial scanning ability, but no significant enhancement of flexibility of closure. On the other hand, there was no evidence that performance on the troubleshooting task was affected significantly by the training (i.e., there was no transfer of training). Although the abilities trained in this study were the dominant factors in the troubleshooting task, they accounted

for only 30% of the variance in performance. It was possible, therefore, that failure to obtain transfer might have reflected the fact that the abilities trained did not account for a significant enough proportion of the ability requirements of the task.

The present study was a follow-up to Levine, et al., and was designed to determine (a) whether intensive training could result in the improvement of spatial visualization ability, (b) whether such improvement would transfer to a task which was dissimilar to the training tasks but which required the same ability for successful performance, (c) whether transfer of training was generalizable across several tasks, and (d) whether ability training improved retention.

RECENT RESEARCH ON SPATIAL VISUALIZATION

Spatial abilities have been extensively investigated historically because of indications in psychometric research that a non-verbal ability factor existed which appeared to be related to mathematical and mechanical aptitude. Actual supporting evidence for the existence of spatial abilities became clearer through the factor analytic work of Guilford and Lacey (1947) and others involved with the Army Air Force Psychological Research Program. Guilford and Lacey (1947) defined two spatial abilities: Visualization, which required the ability to imagine the rotation of depicted objects, the folding or unfolding of flat patterns, the relative changes in position of an object in space, or the motion of machinery; and Spatial Relations (later Orientation), which required comprehension of the arrangement of elements within a visual stimulus pattern. Continued factor analytic work has refined the definition of Visualization and its distinction from Orientation. Eckstrom, French, and Harman (1976) indicated that both abilities required representation in short-term visual memory, but that orientation required only transformation of the stimulus configuration; whereas, visualization required restructuring the figure into components for manipulation and comparison.

Thus defined, spatial visualization is an ability of central importance both to psychometricians concerned with its potential predictive power and to cognitive psychologists concerned with its ability to reveal the operation of several key cognitive processes. A brief overview of recent research on spatial visualization is presented

in this section which focuses on some of the normative characteristics of individuals performing a visualization task and on individual differences in both the cognitive processes involved in visualization and the ability level of subjects.

One of the more extensive investigations of spatial visualization has been carried out by Shepard and his associates (Shepard & Metzler, 1971; Shepard & Feng, 1972; Cooper & Shepard, 1973). For example, Shepard and Metzler (1971) presented subjects with a pair of two-dimensional line drawings of three-dimensional geometric figures, formed by conjoining 10 cubes into a multi-armed figure. These figures were either identical or mirror images within each pair, and were rotated 0°-180° with respect to each other in either the depth plane or the picture plane. Subjects were required to decide whether the figures were the same or different, and to pull a reaction-time lever indicating their decision. To perform this task, subjects reported that they formed a mental image of one figure, rotated it to bring one arm into congruence with the other figure, and then compared the other arms to confirm or disconfirm identity. The similarity between this task description and the definition of spatial visualization offered by Eckstrom, et al. (1976) is striking.

Shepard and Metzler's (1971) results indicated some of the normative characteristics of people performing a task requiring spatial visualization. For all the subjects in the study, reaction-time (RT) in the same-different judgment was a linear function of the difference

between the figures in degree of rotation. The slope of the function relating RT to angular difference in degrees indicated that on the average, subjects could rotate the mental image at a rate of 50°-60° per second. (Wide individual differences were apparent in the slope parameter, however.) The authors suggested that the process of mental rotation was an analog to actual physical rotation, taking place in real time and requiring similar underlying processes.

The technique developed by Shepard and Metzler has been modified to examine other tasks requiring spatial visualization. For example, Shepard and Feng (1972) examined the processes involved in mental paper folding, a task traditionally used to assess spatial visualization ability. They demonstrated that the time taken to decide whether two arrows would meet when an unfolded cube was folded mentally was a function of the number of folds required. More specifically, folds that carried more squares with them appeared to impose a heavier processing load, requiring longer to complete. Therefore, RT was a function of total processing required as indexed by the number and difficulty of folds required. Shepard and Judd (1976) demonstrated that apparent motion could be induced by alternating presentations of the Shepard and Metzler figures, and that this illusion broke down as a function of duration of exposure and degree of angular rotation. That is, for small rotations the illusion of motion persists for rather short durations, but longer durations are required for larger rotations. In this case, however, the rotation is externally driven rather than a mental process, and takes place at a rate of about 1000° per second, as compared with 50°-60° per second for mental rotation.

Studies such as these have argued for the reality of manipulation of mental imagery and have further argued that such manipulation is directly analogous to physical manipulation. These arguments are supported by work which has examined eye movements during the performance of the Shepard and Metzler rotation task (Just & Carpenter, 1976). Just and Carpenter suggested three component processes involved in the performance of this visualization task. Subjects must first search for a distinctive feature of one figure, transform that figure by rotating it into alignment with the other and comparing for a match, and, if a match is obtained, confirm by comparing other distinctive features of the figures. The search and confirmation processes in general are reflected in the intercept of the RT function, and that intercept should increase as the discriminability of stimulus features decreases. The transformation process is reflected in the slope of the RT function; the slope should show a linear increasing function with the degree of rotation required. Eye movement and fixation patterns confirm these processes (Just & Carpenter, 1976).

In spite of several regularities, wide individual differences in the performance of visualization tasks are apparent. These differences include correlations with variables such as sex and quantitative ability, differences in comparison style, and differences in values indicating the efficiency of the various processes being employed.

One of the most frequently cited individual differences in spatial visualization is the advantage of men in performance of tasks requiring this ability. This advantage appears to be developmental, not appearing reliably until after puberty (Maccoby & Jacklin, 1974). The most widely

held theory concerning the source of this advantage is based on cerebral lateralization. The arguement suggests that the right cerebral hemisphere becomes specialized for spatial processing, and that this specialization tends to occur earlier and more extensively in men (cf. McGee, 1979).

A variety of other sex differences in cognitive performance appear to be attributable to the difference in spatial ability. For example, Sherman (1967) has argued rather convincingly that sex differences in field dependence are an artifact of sex differences in spatial ability, and Burnett, Lane, and Dratt (1979) have shown that the usual advantage of males in quantitative ability disappears when covariance with spatial ability is considered. It seems apparent that a wide variety of intellectual functions, as well as mechanical functions are supported by spatial abilities.

An examination of the types of differences which occur in the performance of a visual task was conducted by Cooper (1976) who presented subjects with a variant of the Shepard and Metzler task, in which the stimuli were two-dimensional random line drawings. The comparison stimulus was either identical or one of six foils which varied in similarity to the original. Cooper found that subjects' performance fell into one of two categories on this task. One group, whom she called analytic processors, showed a linear increase in RT as similarity increased on different judgments, and they were slower overall on same judgments. The other, whom she called holistic processors, were faster on same judgments and RT was unaffected by similarity on different judgments. She argued that analytic processors make point-by-point comparisons, while holistic processors make a single judgment based on the overall pattern (as if relying on spatial orientation).

Shepard and his colleagues have noted, in several of their studies, that although the linear increase in slope of the RT function is consistent for individuals, wide differences in the actual value of the slope occur. Cooper and Shepard (1973) noted that individuals seem to fall into fast responders--those who rotate quickly--and slow responders who require more time to rotate images. Egan (1979) has pointed out that slope differences are not the only indication of performance differences in this task. The time required to encode the stimulus and to decide on a response are represented in the intercept of the RT function. Egan (1979) reported individual differences in the intercept value for subjects performing the rotation task, and suggested that the indications of encoding and response differences were important in evaluating visualization performance as well.

Individual differences in visualization have been apparent, since the initial factor-analytic research on spatial abilities. Recent research has suggested that some tentative understanding of spatial ability in terms of hemispheric specialization is possible (McGee, 1979), that performance differences in a visualization task may be due to reliance on other abilities or performance strategies (Cooper, 1976), and that spatial visualization performance may be usefully characterized in terms of the speed of encoding, rotation, and response (Egan, 1979).

METHOD

Two tasks were selected for assessing transfer of training of spatial visualization. They were "Assembly" and "Designs." The former task was obtained from the Flanagan Aptitude Classification Tests; the latter task was developed by the project staff. Figures 1 and 2 present examples of the two transfer tasks.

Assembly Task

This task is derived from the "Assembly Test" in the Flanagan Aptitude Classification Test battery. Subjects are given a series of problems requiring them to visualize the assembly of mechanical parts. Each problem consists of a diagram of an array of machinery-type parts. Each part is labeled with one or more letters which indicates particular places on the part. The parts can be assembled correctly by joining those surfaces or edges labeled with the same letter. For example, an "A" on the top surface of one part and an "A" on the edge of another part indicate that these two parts should be joined together edge to surface. A "B" on the bottom surface of the first part would indicate that it should also be attached to the "B" section of a third part, and so on.

Adjacent to the picture of the unassembled parts is a set of five pictorial representations of various assemblies of the same parts. The subject's task is to imagine how the parts would look when assembled as indicated by the diagram, and then select the correct assembly.

Of the set of nineteen problems in the Flanagan test, four were randomly selected for use in a pretest and the remaining 15 comprised

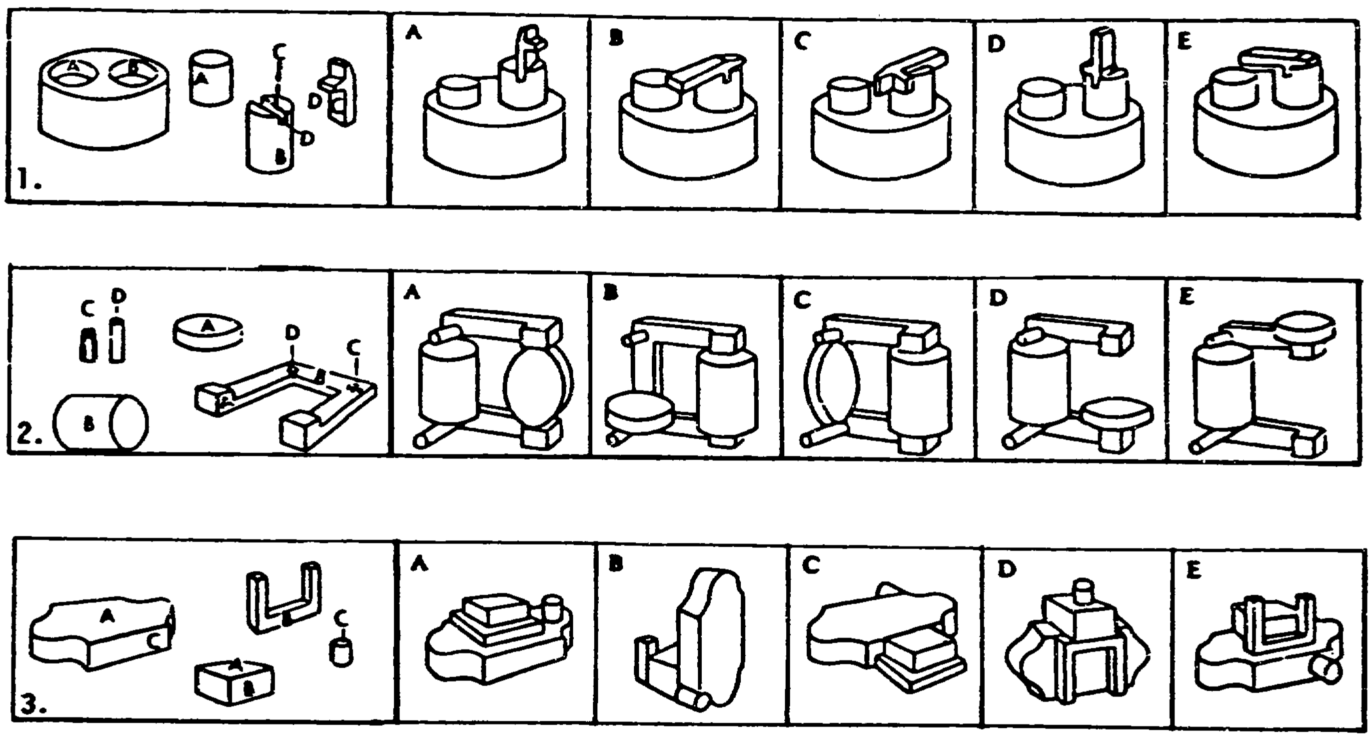
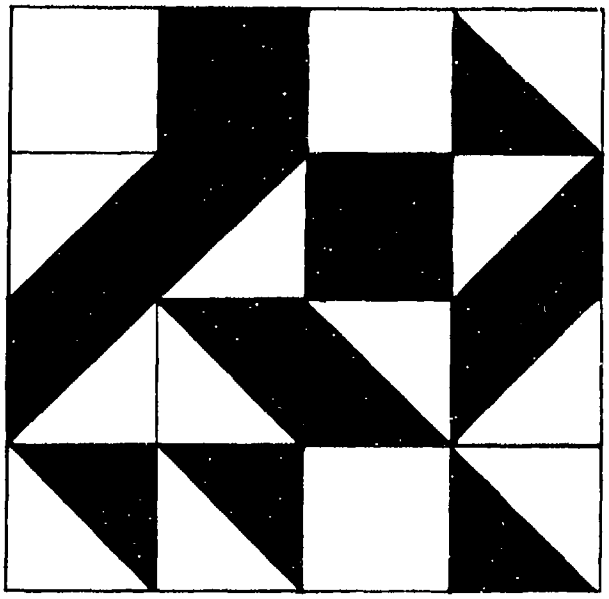


Figure 1. Assembly task.

PROBLEM



SOLUTION

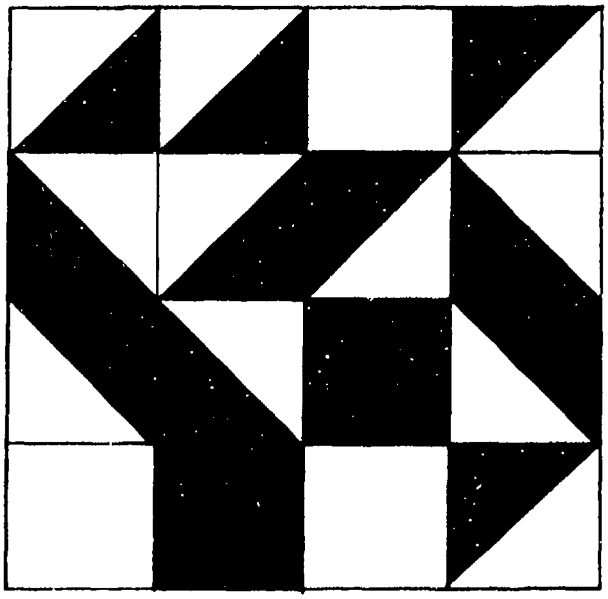


Figure 2. Designs task.

the posttest version of the Assembly task. Exemplary problems were provided in the standard version of the test.

Designs Task

In the Designs task, subjects viewed a series of geometric designs and were asked to reproduce the "flipped" (i.e., turned end-over-end) version of each design. The designs presented to subjects consisted of a 4 x 4 matrix of red and white squares and triangles. Subjects produced the flipped versions by arranging colored cubes on a platform. There were three types of cubes: solid red, solid white and cubes which were half red and half white across a diagonal axis. Only the top surface of each cube was used in making the design, so that the half red and white cube appeared as two triangles--one red and one white.

In order to reproduce the designs in such a manner that the top edge became the bottom edge, and vice versa, subjects had to first form a mental image of the design and mentally flip it until it was in the correct position. This process is central to the visualization ability as it is defined, thus the task was felt to be valid for assessing the effects of ability training.

A set of 40 problems was developed and on the basis of accuracy and completion time measures obtained during pilot testing, the 12 easiest and 12 most difficult were selected for use. From these 24 problems a pretest set of 6, a posttest set of 16, and 2 example problems were randomly selected with the constraint that each set contain an equal number of low and high-difficulty problems.

While the task was developed by project staff specifically to tap the visualization ability, it was felt necessary to substantiate the ability requirements of the task. For this purpose, a set of ability rating scales developed by Fleishman (1972) and his associates was used. These scales permit a group of judges to assess whether or not each of a number of operationally defined abilities is required to perform a task and to what degree. For the purpose of rating the "Designs" task, seven perceptual abilities were considered.

Six ARRO staff members were provided with a detailed description of the task, a sample problem, flow diagrams distinguishing the abilities from one another, and a set of anchored scales each containing examples of tasks requiring various amounts of a specific ability. The raters were to select those abilities required for successful performance of the task using the flow diagrams. For each of the abilities selected, they then were to mark the seven-point scale at the position representing their judgments of the amount of the ability required for successful task performance. Abilities were considered to be essential for the task when there was 80% agreement among raters. For those identified abilities, the median scale rating of the judges was used as the index of the degree of involvement of each ability.

Visualization was identified by all six judges with a median rating of 5.35 on the seven-point scale. Five of the six raters also identified perceptual speed with a median rating of 3.65. No other abilities were identified. The results of this exercise supported the selection of the Designs task for the study.

Subjects

Eighty undergraduate students from local universities served as subjects. They were solicited via advertisements placed in the school newspapers. Subjects were paid approximately $3.35 per hour for their participation. An additional performance-based monetary incentive was associated with all tasks which resulted in total earnings of $4.50-$5.00 per hour.

Training Tasks

The training paradigm was designed to provide subjects with structured practice in using their ability to visualize. It consisted of a series of nine self-administered, largely paper and pencil tasks with built-in feedback. The tasks were either derived from or patterned after standard ability and aptitude tests, or were judged to substantially involve the visualization ability. The Mental Measurements Yearbook (Buros, 1979) was used as a source for aptitude tests which were known to measure the visualization ability. This source also provided factor loadings and correlational data for many of these tests which were used to substantiate that we were, in fact, using training tasks which involved the visualization ability. The Kit of Factor-Referenced Cognitive Tests (French, 1963) was also used as a source of training tasks.

In selecting and developing the training tasks, the following constraints were adhered to:

- The difficulty level of the training tasks had to be challenging enough so that learning could occur.
- The tasks had to be reasonable to implement in a laboratory situation.

- Training had to be diverse enough so that subjects would be given an opportunity to apply the ability in a variety of contexts. This would enable individuals to develop a repertoire of strategies.
- The stimulus materials and tasks used in training had to be as dissimilar as possible from the criterion tasks, while still requiring use of the same ability.

The training tasks selected for use are described below. The Appendix provides examples of items from each of the tasks.

- Task 1 -- "Copying"

  In this task subjects copied a series of asymmetrical line drawings onto graph paper grids. Subjects' drawings had to be in the exact proportions and positions as the originals.

- Task 2 -- "Paperwork"

  For each item, successive drawings illustrated two or three folds made in a square sheet of paper. The final drawing of the folded paper showed where a hole was punched in it. The subject drew holes in a blank square to represent where the punched holes would be when the paper was unfolded. Subjects were provided with paper and hole punches with which they were to check their answers.

- Task 3 -- "Puzzles"

  This task consisted of four different problems, each with its own instructions and each requiring a different type of solution. In general, the problems required subjects to mentally rearrange

objects into different patterns or to mentally rotate two-dimensional drawings in order to arrive at a solution.

- Problem No. 1 was a figure made up of eight squares. The task was to fill the squares with the numbers one through eight so that no two consecutive numbers were adjacent horizontally, vertically, or diagonally.

- Problem No. 2 was a schematic representation of a plot of land containing 12 houses. Subjects were to divide it into six plots of the same size and shape, and each containing two houses, by drawing only four lines.

- Problem No. 3 presented subjects with a drawing of four pieces of chain, each containing three links. The task was to make a closed loop by opening and re-attaching only three links.

- In Problem No. 4, subjects were shown three two-dimensional sketches of rectangular solids composed of cubes. They were to imagine that a hole had been drilled diagonally from one corner to another and then were to indicate which cubes the drill passed through.

- Task 4 -- Formboard

  In this task, subjects viewed pictures of geometric shapes which had been cut into pieces, and were to imagine how the pieces would fit together to form the original shape. Each problem contained two figures--one representing the original shape, and the other, the shape after it had been cut. Subjects

were instructed to carefully study the outline shape and the pieces, then mentally rotate and reposition the pieces within the outline until they could determine how the pieces fit together.

- Task 5 -- Pattern Orientation

  Subjects located a given pattern of circles within a large circle which (the pattern) had been rotated from its original position. Subjects then determined which of several points within the large circle had the same spatial relationship to the pattern as a particular point did to the original unrotated pattern.

- Task 6 -- Upside Down Copying

  This task was similar to Task 1, except that subjects were to copy patterns as they would appear if turned upside down.

- Task 7 -- Stick Problems

  Groups of "sticks" were laid out to form patterns comprised of squares (pictorial representation). In part I of this task, subjects were to remove a specified number of sticks in such a manner that a specified number of squares remained. In part II, subjects were instructed to move a certain number of sticks into new positions so that a certain number of squares resulted.

- Task 8 -- Thinking in Three Dimensions

  Dimension, shape, and surface and interior colors of geometric solids were described to subjects. Various cutting manipulations

were then described, and subjects were to answer questions about the number and colors of the resulting pieces.

- Task 9 -- On the Square

  This task required subjects to determine how abstract geometric shapes could be dissected and then reassembled to form squares. Subjects were presented with a series of paper shapes, each of which was constructed from pieces of a square. The task was to cut each shape into as few pieces as necessary, then reassemble the pieces into a square. The resulting pieces would form a square only if the shape had been cut in a certain pattern.

Ability Level Marker Test

The "Surface Development" test from the Kit of Factor-Referenced Cognitive Tests was used to assess subjects' visualization ability level. In this test, drawings are presented of solid forms that could be made with paper or sheet-metal. With each drawing there is a diagram showing how a piece of paper might be cut and folded so as to make the solid form. Dotted lines indiate where the paper has been folded. One part of the diagram is marked to indicate a surface on the outside of the correctly folded three dimensional object. The subject indicates which lettered edges in the drawing correspond to numbered edges or dotted lines in the diagram. The test is speeded, scored in terms of number correct, and test scores are adjusted for guessing.

Experimental Design

Table 1 presents the experimental design. There were four groups, each experiencing a different sequence of activities as described

TABLE 1

Experimental Design

Group	N	Day 1 Pretests	Days 2-4 Train	Day 5 Posttests	Day 85* Posttests
E_1	20	A	T_1 B T_2	A	A
C_1	20	A	X	A	A
E_2	20	X	T_1 B T_2	A	
C_2	20		T_1 X T_2		

X = No Activity

A = Transfer Tasks (Designs and Assembly)

B = Training Tasks

T = Marker Tests of Ability

* = Only 9 of 20 subjects in E_1 and C_1 returned for testing

below. In Table 1, A represents the transfer tasks (i.e., Designs and Assembly), B is the set of materials selected to train the ability of interest, and X is the designation for unrelated activity engaged in by a group of subjects in lieu of an experimental treatment. T_1 represents the administration of the ability marker test prior to training. T_2 represents the readministration of the test subsequent to training.

Experimental groups (E_1 and E_2) received intensive ability training while a control group (C_1) received no ability training. These three groups also performed on the transfer task. The design addressed these questions: (1) Were the abilities trained?; (2) Did transfer occur?; and (3) Was transfer generalizable across tasks?

The experimental groups differed only in that group E_1 received a pretest on the transfer tasks. The use of a pretest, in which several similar (but not identical) problems from the transfer tasks are administered prior to any training, permits the collection of baseline measures of criterion task performance. Scores on this pretest can then be used to adjust scores on the posttest in order to eliminate any bias in the posttest scores which may be due to initial performance differences between experimental and control groups on the transfer task. A potential disadvantage of such pretesting, of course, is that the pretest itself may provide some training or practice that positively transfers to the posttest situation. In order to account for this, Group E_2 was included. Comparisons on the posttest between E_1 and E_2 reveal any effect due to practice on the criterion task during the pretesting phase.

Group C_1 is a control group which did not receive any training. By comparing posttest performance for groups E_1 and C_1, the question of transfer is addressed. Group C_2 is a control group which received only the ability marker tests.

The question of whether the abilities were trained is addressed by comparing performance on T_1 and T_2 for the two experimental groups. If performance on T_2 is substantially greater than T_1 in each of these groups, and if Group C_2 does not demonstrate a significant improvement across administrations, then it can be concluded that success has been realized in training the abilities.

The need for an ability marker test requires some explanation. In most transfer research, the effect of training is assumed to be reflected in the posttest comparisons between experimental and control groups on the transfer task. In the present effort, it is possible for performance on one of the transfer tasks to be unaffected by training, despite having successfully trained the ability under study. This is because the Designs transfer task requires (for successful performance) more than the visualization ability being trained. Enhanced visualization may not contribute enough to the performance of the Designs task to result in improved proficiency. To identify whether or not transfer findings are specifically due (at least in part) to the enhancement of visualization, a marker test which is a "pure" measure of that ability is required.

Procedure

Subjects were randomly assigned to the four groups and participated in one experimental session daily for up to five consecutive days.

In the first session (pretest) shortened versions of the "Designs" and "Assembly" tasks were administered; sessions two, three, and four consisted of ability training and administration of the ability marker test preceding and following training; the final session (posttest) consisted of the administration of the Designs and Assembly tasks using a different and larger set of problems. Subjects were individually tested on the transfer tasks, and received training, and were administered the ability marker tests in groups of five.

On first reporting to the laboratory, subjects were briefed on the general nature of the study and the types of tasks they would be performing. They were told that they would be performing a series of tasks which involved imagining or formulating mental images of how objects would look if they were repositioned or changed. All tasks would require the participants to manipulate mental images of objects in some manner such as rotating, inverting, dissassembling, or folding. Subjects were informed that they could earn additional money in excess of the amount they were guaranteed for participating in the study, and that this amount was dependent upon the quality of their performance.

Subjects were next instructed in the nature and procedure of the Designs task.* This included presentation of a sample problem. Subjects were given a set of 10 red and 10 white blocks and 16 blocks which were half red and half white across the diagonal, and a platform on which to place the blocks. They were told that they would be shown a series of six designs which they were to produce flipped versions of

*The order of administration of the transfer tasks was counterbalanced within groups.

using the colored blocks. They were instructed to imagine how the design would look when flipped end-over-end so that the bottom edge became the top edge and vice versa, then place the blocks one-at-a-time on the platform, duplicating their image of the flipped design.

Subjects were not permitted to turn over any blocks on a horizontal axis while constructing a design. This was to prevent any strategy based on physically turning parts of the design upside down which would circumvent the need to visualize. Subjects were instructed not to construct the design or parts of it off the platform, but rather to place one block at a time on the platform. However, they were allowed to reposition blocks at any time if they desired, but only by moving or removing them one-at-a-time.

In order to encourage both speed and accuracy in this task, a point system based on these two factors was devised. Subjects were told that they would earn 100 points for each correctly completed design and that, from this total, five points would be subtracted for every 30 seconds it took to complete the design. No points were earned for incorrect designs, and a problem was terminated if not completed within 10 minutes.

Following the instructions, subjects were administered the pretest. It consisted of two practice problems plus six problems which had been randomly drawn from the 24 originally developed. Three problems of each of two difficulty levels were included. The order of presentation was randomized and was the same for all subjects.

The experimenter displayed the designs one-at-a-time to the subject. The subject indicated when he had completed the design, and at that time, accuracy and elapsed time were recorded. Subjects were told whether the design was correct or incorrect; the blocks were disassembled; and the next problem was displayed.

The Designs task pretest required approximately 20 minutes. When the Designs task was finished, subjects took a 10-minute break, after which they were given instructions for the Assembly task pretest. Subjects were told that they would be performing a task which required visualizing the assembly of mechanical parts. A diagram was used to explain to subjects how the parts were labeled to indicate the manner in which they fit together. Subjects were informed that in each problem there would be a picture of several unassembled parts with various edges and surfaces labeled and five pictures of the same parts assembled, only one of which was correct. Their task was to select the correct assembly. A practice problem was administered and questions were answered.

To encourage speed and accuracy, subjects were told that they would receive 100 points for each correct answer. From this, ten points would be subtracted for every 30 seconds it took to arrive at the answer. No points were earned for incorrect responses, and a problem was terminated if not completed within five minutes.

Following the instructions, subjects were administered the pretest which consisted of a practice problem plus four test problems. The order of problem presentation was randomized and the same for all subjects.

The experimenter presented the problems one-at-a-time to the subject. The subject indicated his response on a separate answer sheet, by circling the correct assembly. Accuracy and elapsed time were then recorded by the experimenter and the next problem was displayed. The Assembly task pretest required approximately 10 minutes. The entire session on day one lasted approximately 1½ hours.

The second, third, and fourth days consisted of the training phase of the experiment. Subjects participated in groups of five in a single 4-hour session on each of these days.

On the second day, the ability marker test for visualization was administered. Subjects were then introduced to the training phase of the experiment. Specific task instructions were given by the experimenter, and a sample problem was shown and explained prior to each training task. Tasks 1-3 were administered on the second day, tasks 4-6 on the third day, and tasks 7-9 on the fourth day.

Training tasks were self-administered; however, subjects were encouraged to ask questions about anything they didn't understand at any time during the task. Feedback was built into each training package and consisted of descriptions and/or diagrams of correct solutions which were displayed immediately following each page of problems. Subjects were instructed to complete a page of problems, then to compare their work with the correct solutions before continuing with the task.

Subjects worked at their own pace through each task. Because training occurred in a group situation, subjects were required to wait until everyone in the group had completed the previous task before

proceeding to the next one. Tasks varied in terms of average completion time from 45 to 90 minutes. The tasks were self-scored, enabling subjects to determine how well they did in comparison with the maximum possible score. Subjects were carefully monitored to insure accurate scoring. At the end of the last training session, the ability marker test was readministered.

On day 5, subjects returned for the Designs and Assembly posttests. The posttests were administered in the same order as the pretests. Instructions for the Designs task were repeated followed by the two practice problems used in the pretest. Each subject was then individually administered 16 problems, representing 8 problems at each of two difficulty levels. The order of problem presentation was identical for all subjects and was randomized with the constraint that the first half and the second half of the problem sequence each contained four problems of each difficulty level.

Following the Designs posttest, the Assembly posttest was administered. Instructions for the Assembly task were repeated followed by the practice problem used in the pretest. Each subject was then individually administered 15 problems. The order of problem presentation was randomized and was identical for all subjects.

Subjects earned points in the two posttests according to the same formula utilized in the pretests. At the end of the session, the amount of incentive pay earned by the subject for all tasks was computed and added to the fee guaranteed for participating in the experiment. Subjects were paid and questions about the nature and purpose of the study were answered at that time.

The preceding described the treatment of subjects assigned to Group E_1. Subjects assigned to Group E_2 were treated in an identical fashion to Group E_1, except that the first day's session (pretest) was omitted. Subjects in Group C_1 received both the pretest and post-test, but did not receive ability training. Subjects in Group C_2 received only the ability marker test. A total of eighty subjects were tested according to the design in Table 1.

In order to assess the stability of any impact of training over time, nine subjects from E_1 and nine subjects from C_1 were retested on the posttest version of the transfer tasks, approximately 85 days after initial administration of the posttests. Subjects were selected for the follow-up study from among earlier participants on the basis of their availability, and were paid $25.00 plus a performance-based monetary incentive. The mean number of days elapsing between day 5 and retesting was 86.5 (S.D. = 9.11) for the E_1 group and 84.0 (S.D. = 11.47) for the C_1 group. Subjects were read the original task instructions and administered the identical transfer tasks used earlier. The same performance measures were taken.

RESULTS

Analyses were carried out on the scores obtained from the ability marker test and the two transfer tasks. Performance measures for the transfer tasks included accuracy, time to solution, and time to correct solution for each problem.

Mean scores on both administrations of the ability marker test were contrasted for the groups receiving training (E_1 and E_2) and the untrained control group (C_2) in order to determine whether the training regimen resulted in improvement of the ability being trained. There was no evidence that visualization was successfully trained. Figure 3 shows the mean scores for the several groups who were given the ability test. Both the two trained groups and the untrained control group showed improvement between administrations of the marker test, but the differences were not statistically significant.

Assembly Task

A two between-subject, one within-subject analysis of variance was carried out on the data obtained from the Assembly task posttest. The between-subject variables were groups and order (whether the Assembly task was performed prior to or subsequent to the Designs task). The within-subject variable was trial block. There were three groups, two orders, and three blocks of five problems each. Analyses were carried out for each of the three measures of performance defined earlier.

Of principal importance in this analysis were the main effect of groups and the group x trial blocks interaction effect. Although we

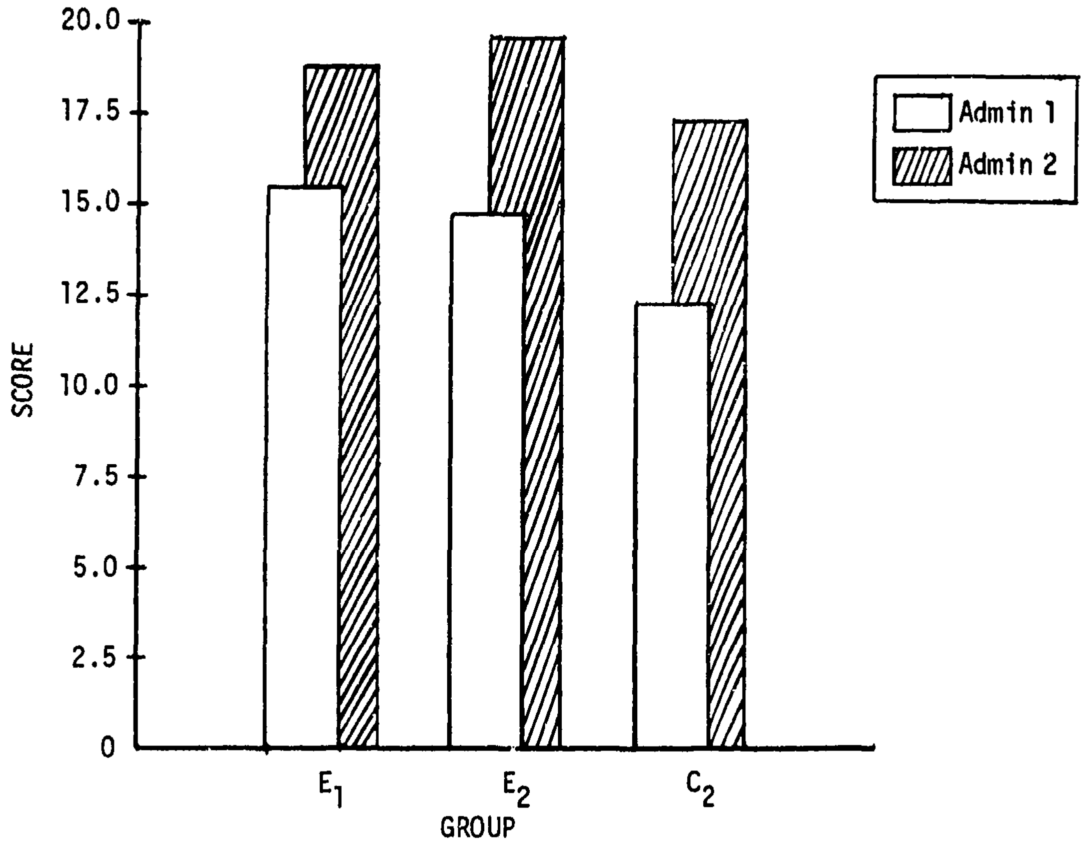


Figure 3. Mean scores on visualization marker test.

were mainly concerned with evaluating the effect of the pretest here, we were also interested in whether the influence of the pretest varied as a function of practice on the task during the posttest.

The results indicated that the only effects of interest which were statistically reliable were for the time to solution performance measure. Here, the group x trial block interaction was the only significant effect [$F(4,108) = 3.20$, $p < .05$]. Contrasts among means indicated that while both pretested groups had mean times to solution which were approximately equal in the first two blocks of problems, E_2 required significantly more time than E_1 for the final block. The relationship is shown in Figure 4.

Although there was little technical interest in other findings from the analyses of variance, it should be noted that the main effect of trial block was significant for each performance measure. Essentially, subjects took longer to solve problems in succeeding trial blocks. Accuracy was significantly better for problems in the second block than either the first or third. Table 2 presents the group means for each of the dependent variables.

In order to assess the effect of training on posttest performance, the data from Groups E_1 and C_1 were subjected to analyses of covariance. The analyses of covariance had the effect of adjusting posttest scores for individual differences on the pretest (i.e., essentially matching the groups on the basis of the pretest). The covariate was the mean pretest score for each subject on each of the three dependent variables.

The analyses of covariance failed to reveal any significant effects of interest. Groups E_1 and C_1 (both pretested, but only the former

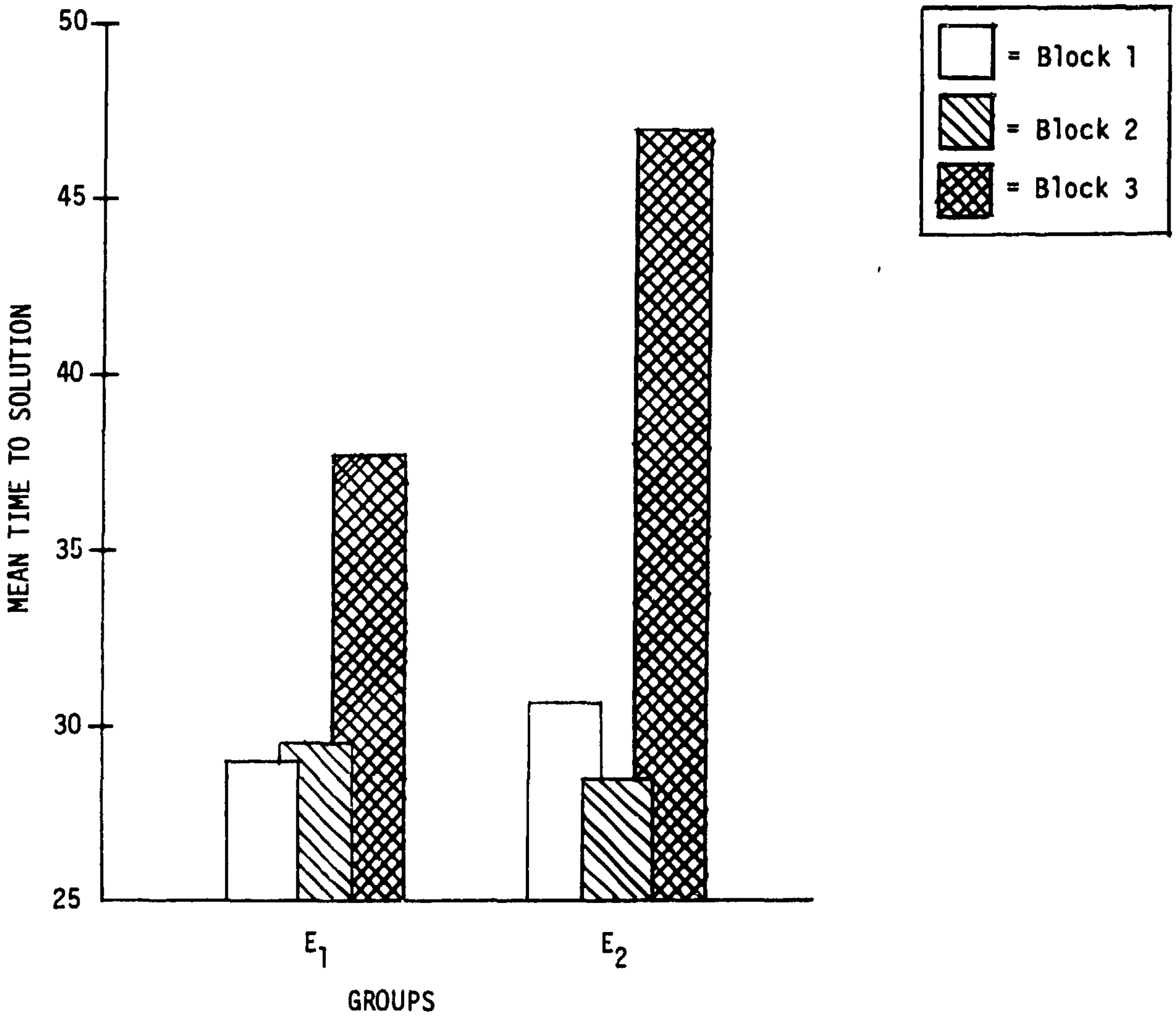


Figure 4. Mean time to problem solution for pretested groups as a function of trial block on the Assembly task.

TABLE 2

Assembly Group Means

	Group		
Performance Measure	E_1	C_1	E_2
Accuracy (%)	75 (70)	84 (81)	76
Time to Solution (sec)	32 (32)	35 (33)	36
Time to Correct (sec)	31	34	35

trained) did not differ on any measure. There were no significant group x trial block interactions. Figure 5 shows the mean scores for the two pretested groups on each block of problems for accuracy and time to solution. Averaged over all subjects in the two groups, adjusted mean accuracy was 79%, and time to problem solution was 33 seconds.

The data obtained on the retention test for Groups E_1 and C_1 were subjected to analyses of variance using accuracy and time to solution as dependent measures. No significant group differences were revealed. Only the main effect of trial block was statistically reliable. Training did not enhance retention. Group means are given in Table 2 in parentheses.

Designs Task

A two between-subject, two within-subject analysis of variance was carried out on the data obtained from the Designs posttest. The between-subjects variables were groups and order. The within-subject variables were blocks of trials and problem difficulty. There were three groups, two orders, and two blocks of eight problems, each block containing problems of two levels of difficulty. Analyses were carried out for each of the measures of performance defined earlier.

Of primary interest here, were the main effect of groups and the group x trial block and group x problem difficulty interactions. In this analysis we were interested in the effects of the pretest, and whether the effect varied as a function of practice on a difficulty of the task.

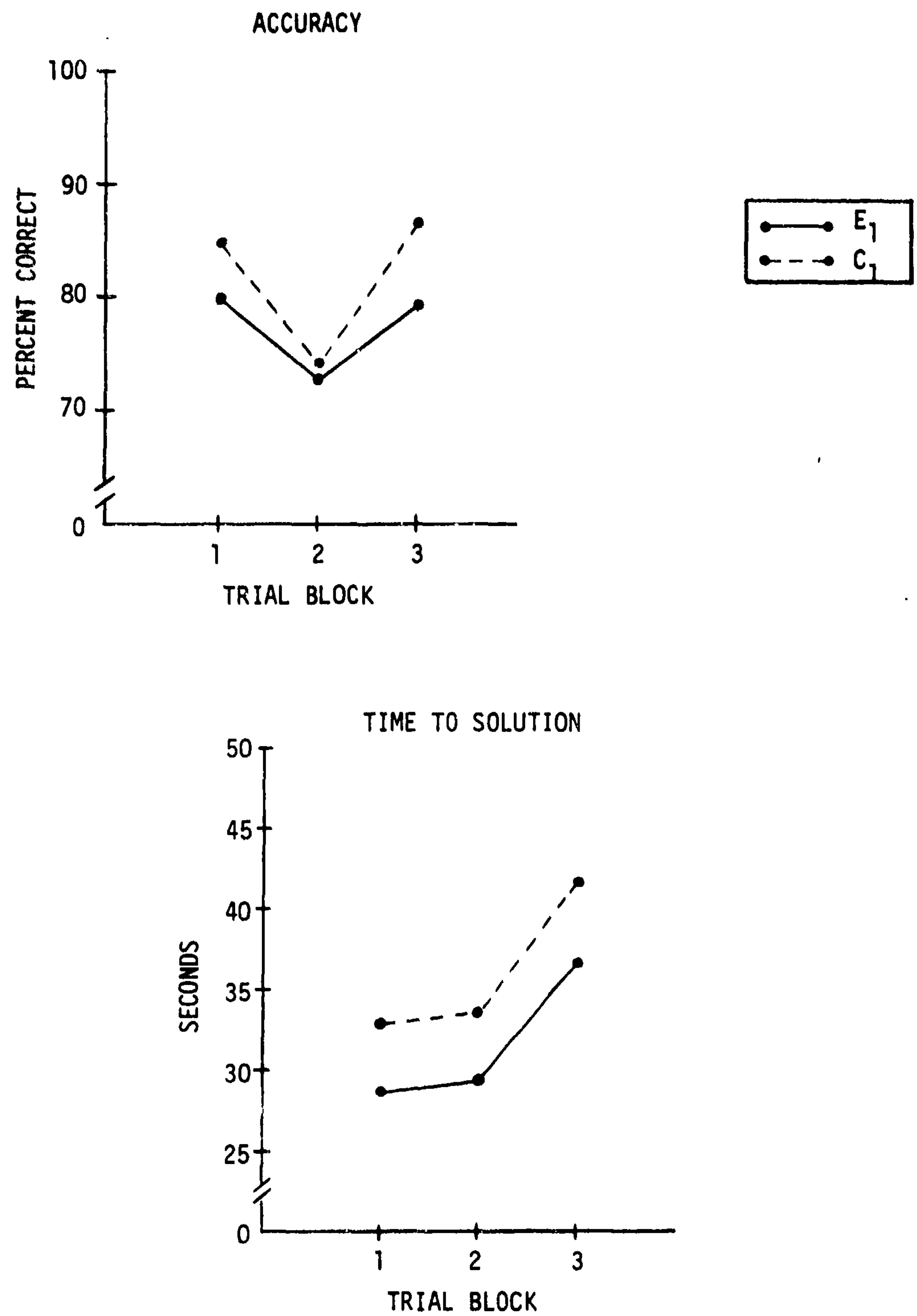


Figure 5. Adjusted mean Assembly performance of trained and untrained groups as a function of trial blocks.

The results indicated that the only effect of interest which was statistically reliable was for the time to solution performance measure. Here, the group x problem difficulty interaction was significant [$F(2, 54) = 3.98$, $p < .05$]. Contrasts among means indicated that E_2 solved hard problems significantly more slowly than E_1 (see Figure 6).

The main effects of problem difficulty and trial block were significant for the time to solution measure only--but they were of little technical interest. It took significantly longer to solve problems which were of greater difficulty and which were presented in the first block of trials rather than the last. Table 3 presents the group means for each of the dependent variables.

Consistent with the approach taken in analyzing the data from the Assembly task, analyses of covariance were carried out on the data from Groups E_1 and C_1 to evaluate the effect of training. The analyses of covariance adjusted posttest scores for individual differences on the pretest (i.e., essentially matching the groups on the basis of the pretest). The covariate was the mean pretest score for each subject on each of the dependent variables.

The analyses of covariance failed to reveal any significant effects of interest. Groups E_1 and C_1 (both pretested, but only the former trained) did not differ on any measure. There were no significant group x trial block or group x problem difficulty interactions. Figure 7 shows the mean scores for the two pretested groups on each block of problems for each of the dependent variables evaluated. Averaged over all subjects in the two groups, adjusted mean accuracy

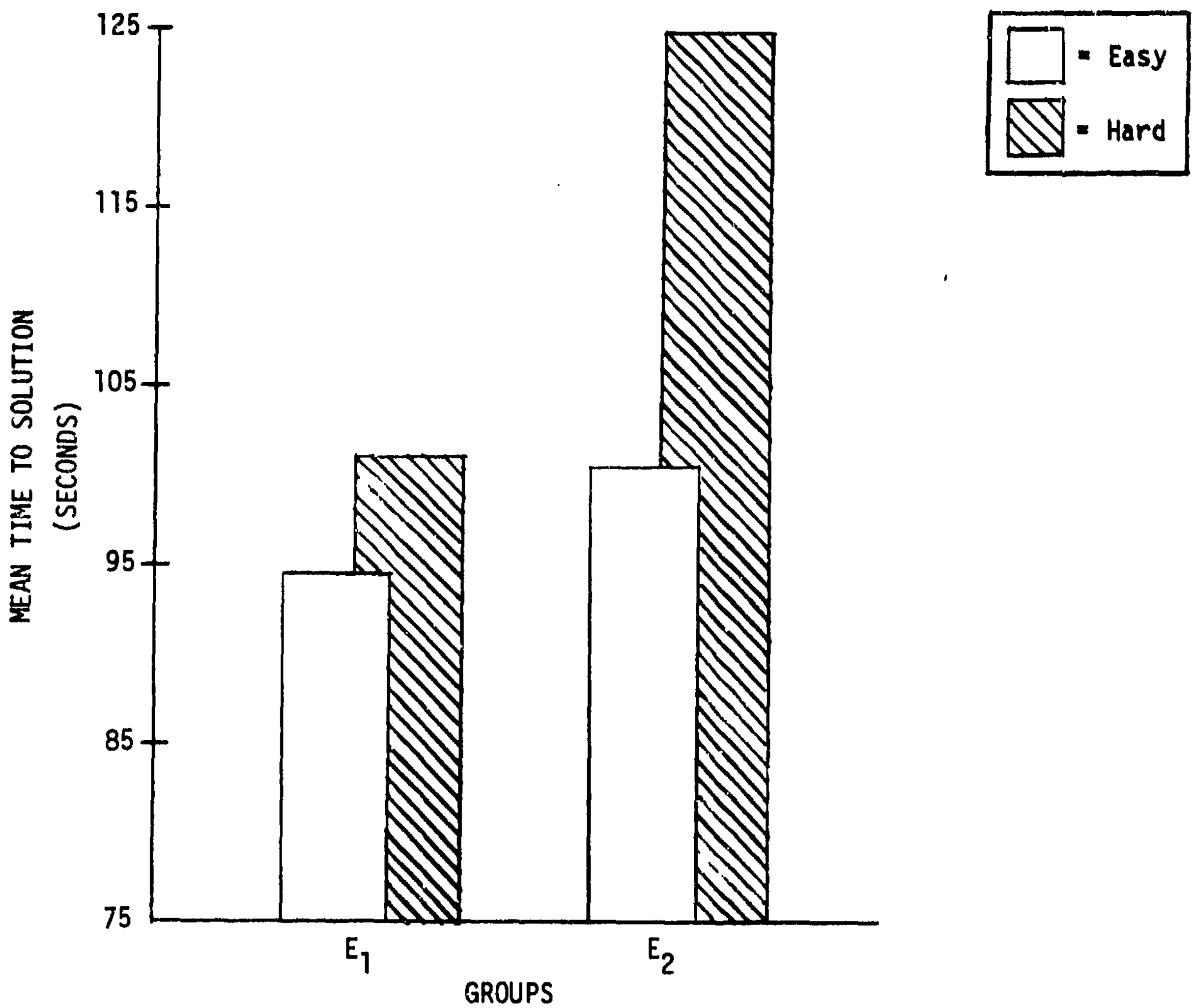


Figure 6. Mean time to problem solution for pretested groups as a function of problem difficulty on the Designs task.

TABLE 3

Design Group Means

Performance Measure	Group		
	E_1	C_1	E_2
Accuracy (%)	88 (91)	93 (97)	88
Time to Solution (sec)	97 (106)	94 (85)	112
Time to Correct (sec)	55	51	47

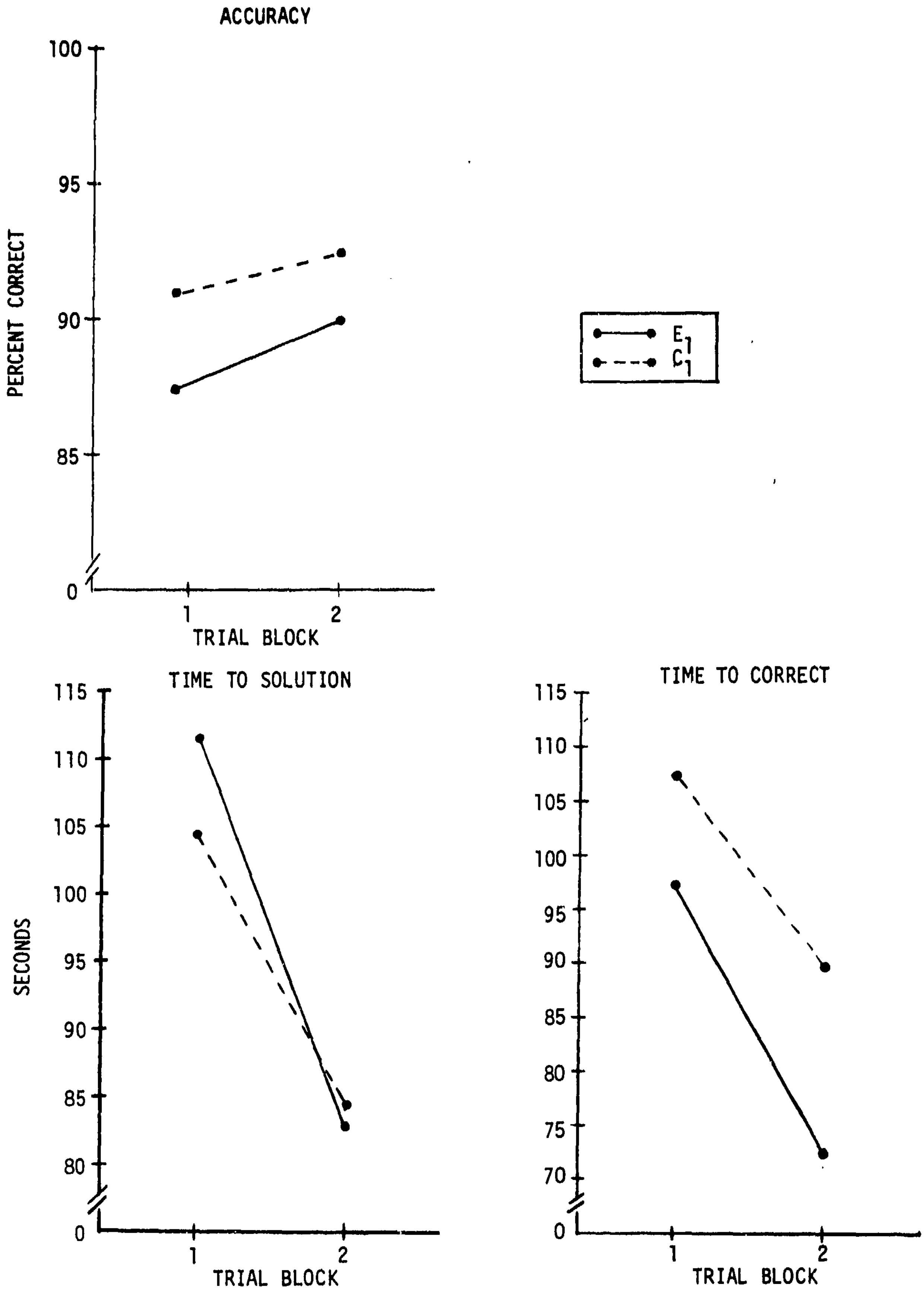


Figure 7. Adjusted mean Designs performance of trained and untrained groups as a function of trial blocks.

was 90%; time to problem solution was 95 seconds; and time to correct solution was 91 seconds.

The data obtained on the retention test for Groups E_1 and C_1 were subjected to analyses of variance using accuracy and time to solution as dependent measures. No significant group differences were revealed. Only the main effects of trial blocks and difficulty and their interaction were statistically reliable. Training did not enhance retention. Group means are given in Table 3 in parentheses.

DISCUSSION

Extensive practice on tasks requiring the ability of spatial visualization did not result in enhancement of the ability; nor did such practice lead to positive transfer of training on two tasks which were dissimilar to the practice tasks but required spatial visualization for successful performance. These findings are consistent with earlier results reported by Levine, et al. (1979). While these authors reported marginal success in enhancing one of two abilities trained, they were unable to demonstrate transfer to an electronic troubleshooting task which, in part, required the trained ability for successful performance. Levine, et al. argued that failure to obtain transfer might have reflected the fact that the ability successfully trained, spatial scanning, did not account for a sufficient proportion of the ability requirements of the troubleshooting task. Thus, improvement on spatial scanning may not have contributed substantially enough to the quality of subsequent troubleshooting performance.

The present study used transfer tasks which required little, if any, ability other than spatial visualization; yet, there was no evidence of transfer of training.

On the assumption that ability training may be effective only for individuals who bring a relatively low level of the ability to the task, additional analyses were carried out. Subjects in Group E_1 were partitioned into the five highest and five lowest scorers on the first administration of the visualization marker test. Performance of each subgroup was compared to that of the untrained control group. Analyses of

covariance were used on this reduced sample with mean pretest scores as the covariate. The results indicated no differences between either the high ability or low ability subgroups of trained subjects and the untrained control group on either the Assembly or Designs task.

In order to assess the degree to which the transfer tasks related to the ability trained, correlation coefficients were computed between the scores on the first administration of the ability marker test and mean transfer task scores on the posttest, for all trained subjects. Time to correct solution was used as the measure of posttest task performance. The average correlations were -.40 and -.33 for the Assembly and Design tasks, respectively. The negative values are due to smaller times being associated with improvement in performance. The correlation between performance on the two transfer tasks was .20, suggesting that they were substantially different from each other. None of the correlation coefficients were significantly different from zero.

The training regimen adopted in this study was based upon extensive self-paced practice with feedback using a broad array of tasks having a wide range of difficulty and known to require spatial visualization ability. Fifteen hours of training were given over a three-day period. As Levine, et al. have pointed out there are other possible training approaches which might have had an impact on criterion task performance. For example, training could have been made even more extensive and distributed over a longer period of time in order to increase it potential effectiveness. For practical reasons this could not be carried out in the present study.

In addition to a variety of modifications in the phasing and amount of training provided, there are other approaches which could have been adopted. Levine, et al. suggested the training of strategies which result in successful performance on tasks having similar ability requirements. Alternately, we could have obtained data on specific behaviors involved in the criterion task (which were relevant to the ability) and developed a training paradigm around those behaviors. It might also have been possible to train the information processes assumed to underly spatial visualization. According to Egan (1979) these would include search, transformation, and confirmation. We know of no basis for choosing among these or other approaches to ability training. The amount and type of training necessary to improve an ability is a research issue which has not yet been addressed.

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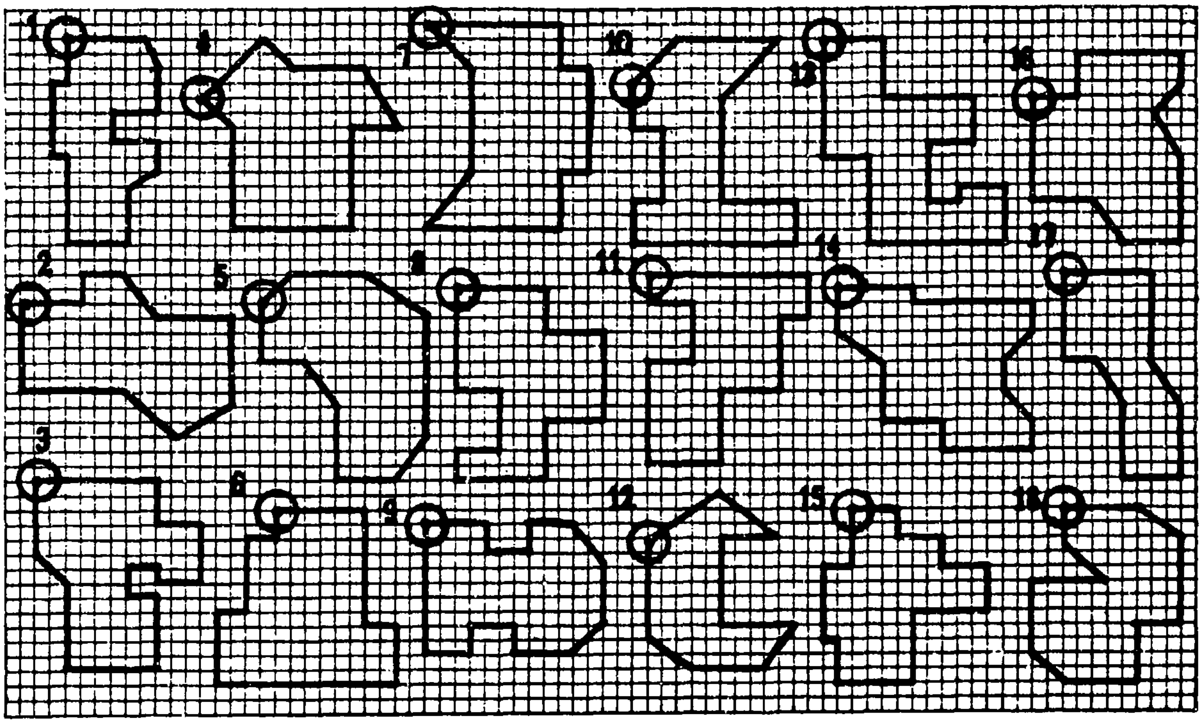
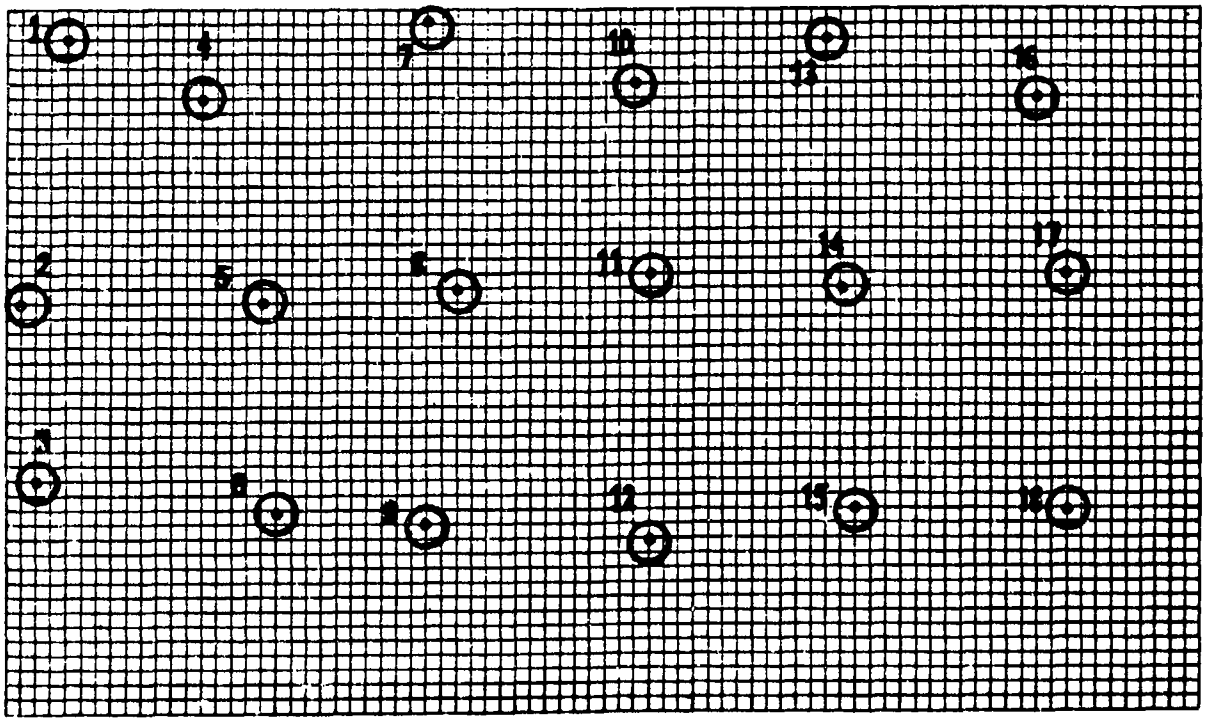
APPENDIX

Examples of Training Tasks

Task 1 -- Copying

Copy each pattern onto the grid at the bottom of the page. Begin each pattern at the circled dot. Your drawings should look exactly the same as the patterns shown, i.e., identical in size, shape, and proportions.

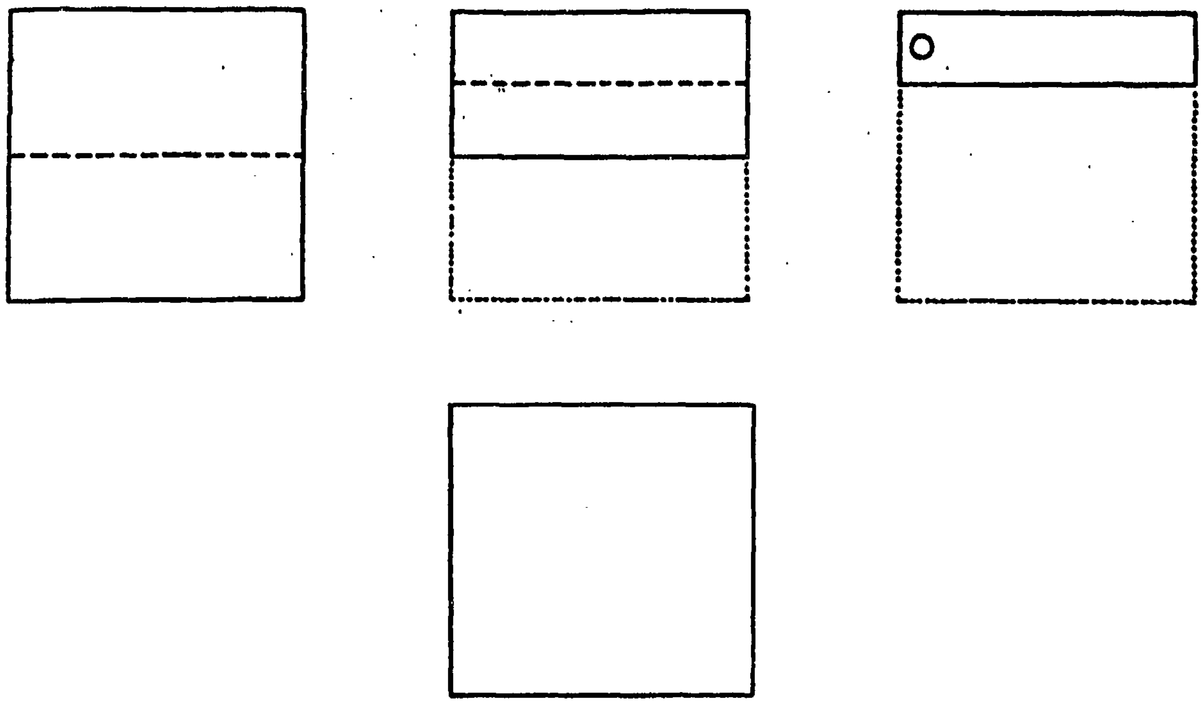




Task 2 -- Paperwork

Draw holes in the blank square to show how the paper will look when it is unfolded. After each problem, fold a piece of paper and punch a hole in it following the steps pictured in the diagrams. Then unfold the paper and compare the location of the holes to your drawing.

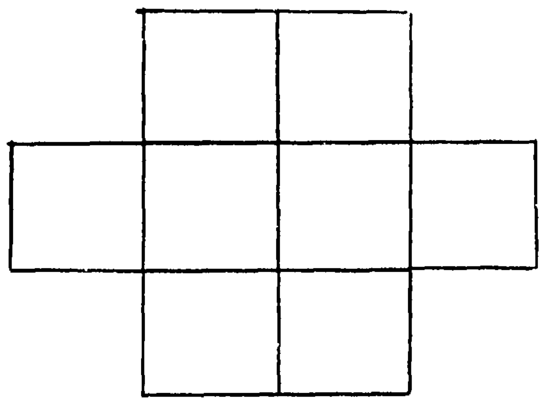
1.



Task 3 -- Puzzles

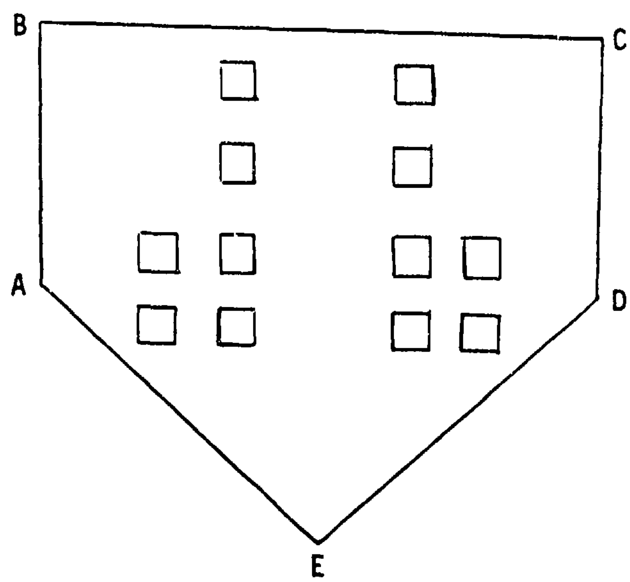
PUZZLE #1

Fill the squares with the numbers one through eight, so that no 2 consecutive numbers are adjacent horizontally, vertically, or diagonally.



PUZZLE #2

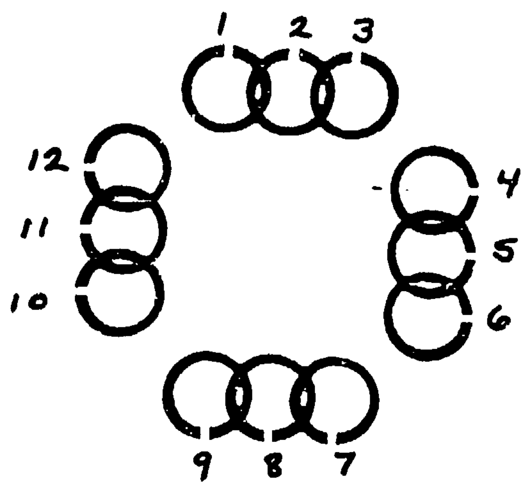
Using only <u>4 lines</u>, divide the land into 6 plots all of the same size and shape with 2 cabins on each plot.



PUZZLE #3

Open and re-attach 3 links to make a closed circle.

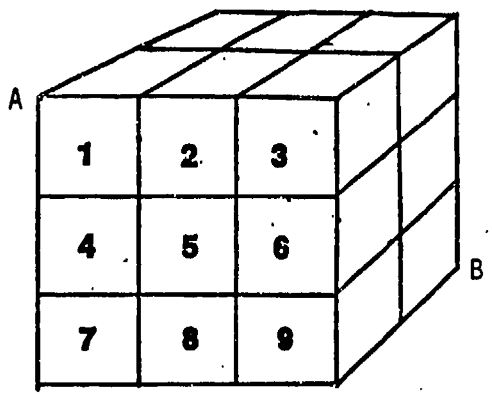
Circle the number of each link you want to open. Write next to it the number of the links to whicn it shoula be joinea.



PUZZLE #4

Problem #1

A solid consists of 18 cubes arranged 3 wide, 3 high, and 2 deep. The front row of cubes is labeled A-1 through A-9 as shown in the drawing. The second row is labeled B-1 through B-9.

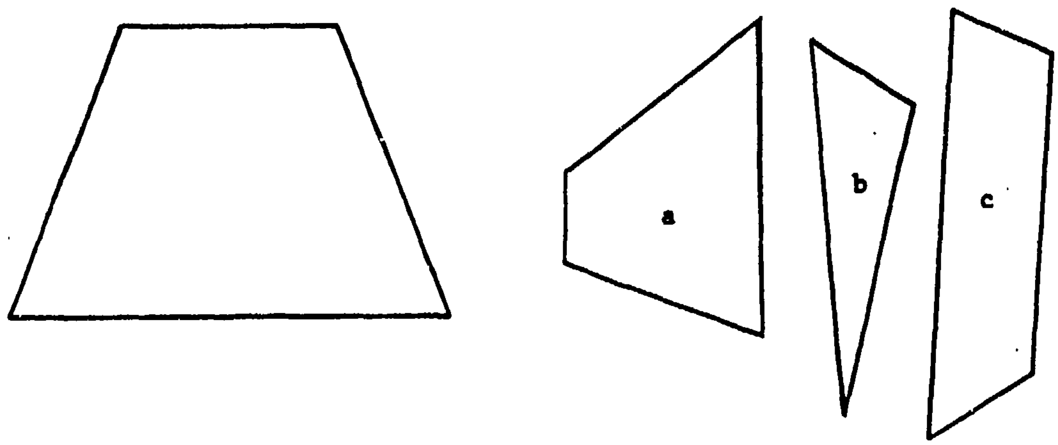


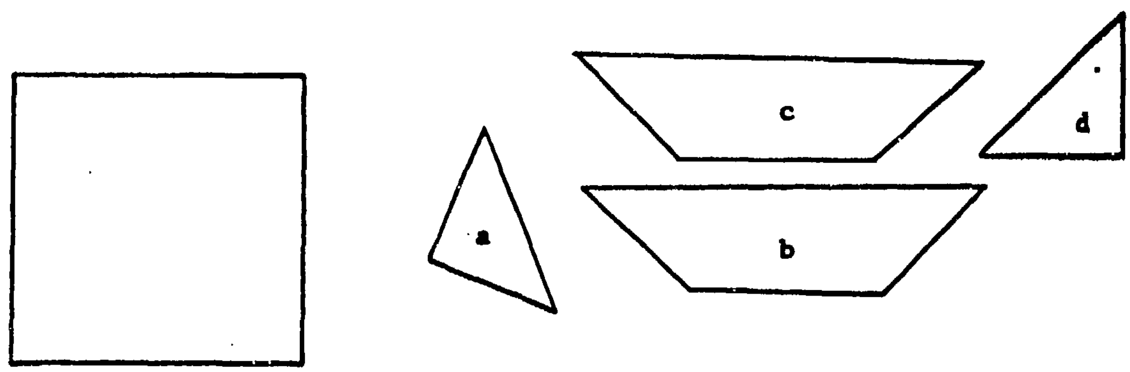
A diagonal is drilled by a very fine drill from one corner A (left, top, front) to the farthest corner B (right, bottom, back) If we ignore the thickness of the drill, so that the diagonal is a geometric straight line, which cubes will the diagonal pass through?

Answer:______________________________

Task 4 -- Formboard

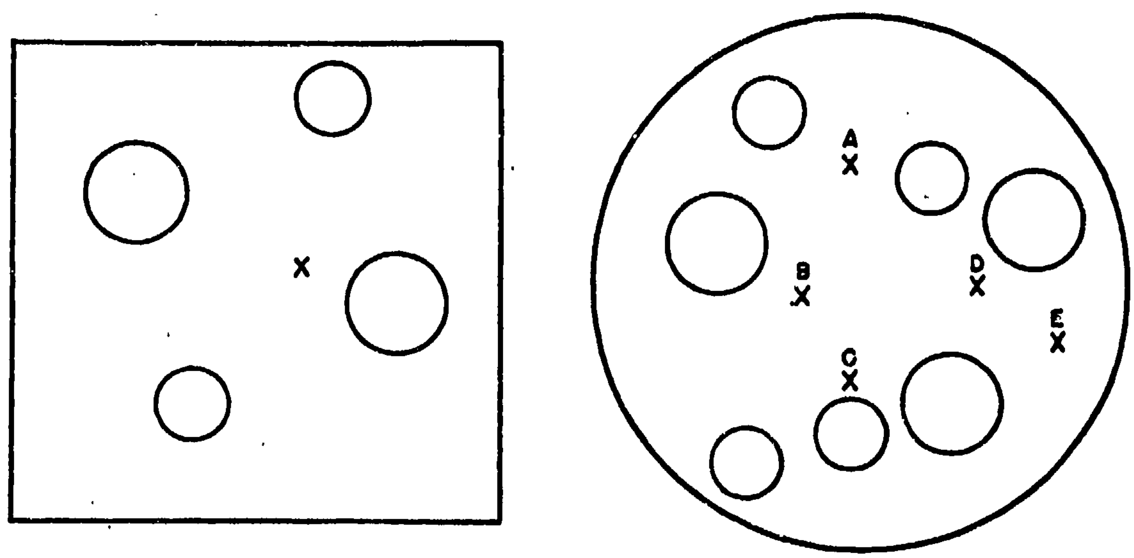
Show how the pieces on the right fit together to form the shape on the left. Do this by drawing lines in the shape on the left.





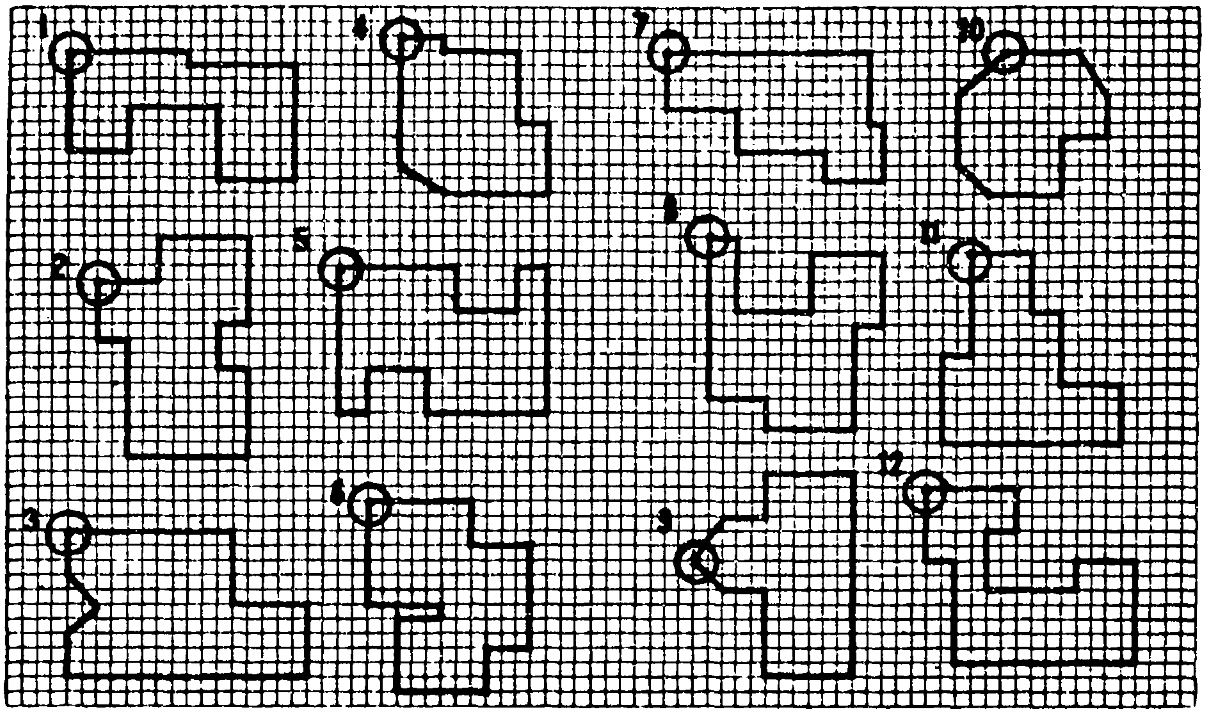
Task 5 -- Pattern Orientation

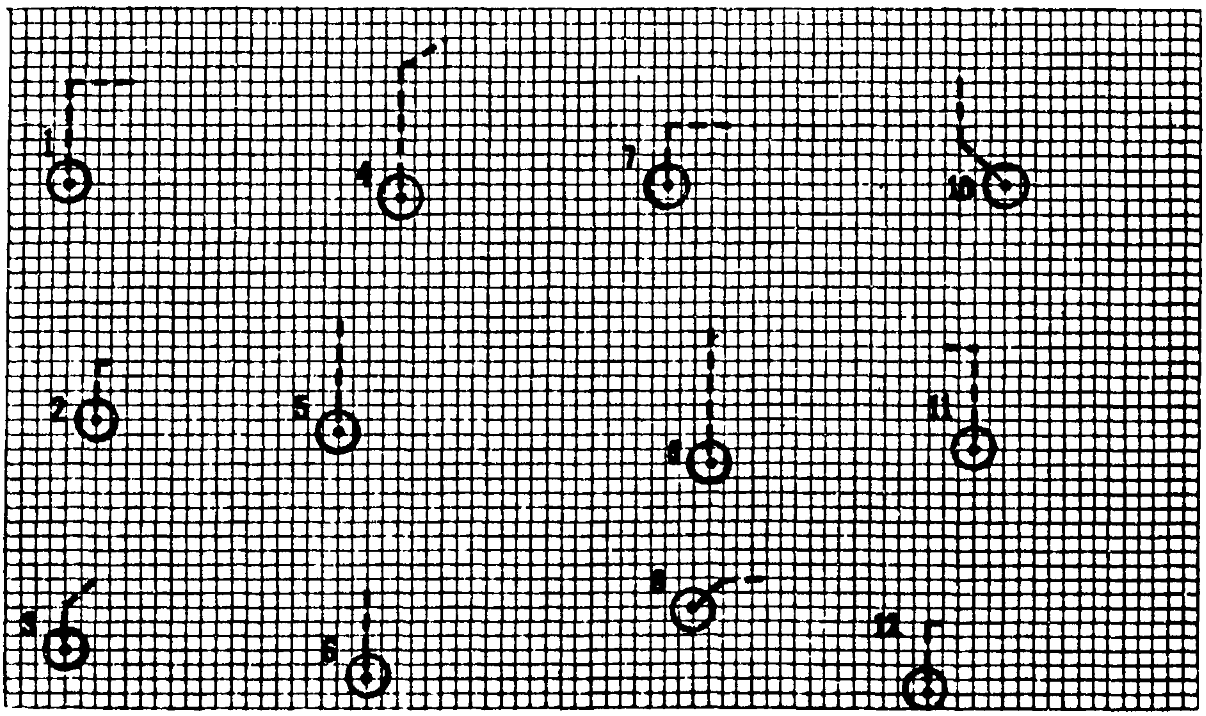
In the figure on the right, locate the pattern of circles shown on the left. Put a check mark in each of the circles making up the pattern. Next decide which one of the lettered crosses bears the same relationship to the pattern as the cross in the square on the left. Then draw lines connecting the cross to each of the circles.

1. 

Task 6 -- Upside-Down Copying

This task is identical to Task 1, except that you are to copy the patterns upside down as they would appear if they were turned over, putting the top at the bottom.

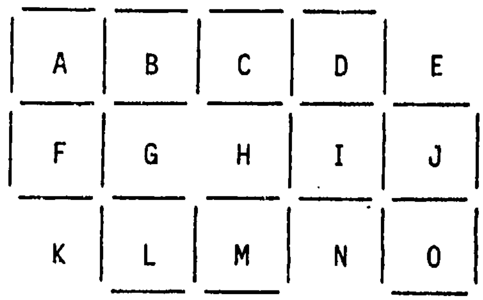




Task 7 -- Stick Problems

Indicate with hatch marks which sticks are to be removed. Every stick remaining must be part of some square.

1. Remove 2 sticks and leave 9 squares.



Task 8 -- Thinking in Three Dimensions

Answer the questions by filling in the blanks with a number. Sketching the blocks may be helpful.

The entire surface of a 2-inch cube of wood is painted black and the block in cut into 1-inch cubes.

1. How many 1-inch cubes have some black on them? ________
2. How many 1-inch cubes have three black sides? ________

The four narrow sides of a 1" x 1" x 4" block are painted red. The top and bottom are painted blue. The block is then cut into 1-inch cubes.

3. How many cubes are there? ________
4. How many cubes have both red and blue sides? ________
5. How many cubes have one red side and two blue sides? ________
6. How many cubes have no painted sides? ________

Two sides of a 3-inch cube that are next to each other are painted black and the material cut into 1-inch cubes.

7. How many cubes have only four unpainted sides? ________
8. How many cubes have only one unpainted side? ________
9. How many cubes have only two unpainted sides? ________
10. How many cubes have both unpainted and black sides? ________

Task 9 -- On the Square

In front of you is a series of paper shapes, each of which was constructed from pieces of a square. Your task is to cut each shape into pieces, then reassemble the pieces into a square. The resulting pieces will form a square only if the original shape has been cut in a certain way.

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Groton, CT 06340

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Department of Administrative Sciences
Naval Postgraduate School
Monterey, CA 93940

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Washington, DC 20374

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Code 6021
Naval Air Development Center
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Annapolis, MD 21402

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Vermillion, SD 57069

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Arlington, VA 22202

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Portland State University
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Department of Psychology
University of Colorado
Boulder, CO 80302

1 Dr. Peter Polson
Dept. of Psychology
University of Colorado
Boulder, CO 80309

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R-K Research & System Design
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Department of Psychology
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Providence, RI 02912

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Dept. of Psychology
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Box 11A, Yale Station
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Bolt Beranek & Newman, Inc.
50 Moulton Street
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Laurel Ridge
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1 Dr. Perry Thorndyke
The Rand Corporation
1700 Main Street
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1 Dr. Douglas Towne
Univ. of So. California
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1845 S. Elena Avenue
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Perceptronics, Inc.
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Minneapolis, MN 55455

1 Dr. Gershon Weltman
Perceptronics, Inc.
6271 Variel Avenue
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1700 Main Street
Santa Monica, CA 90406

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